Chapter

3

DESIGN AND INTEGRATION

Most of the designing works of the entire laser cutting system were carried out with the help of AutoCAD Mechanical Desktop 1.1. The designs were drawn in 3D with every parts designed in a separate CAD file and assembled into a module. Then, each module was assembled to form the whole laser cutting system. Since the drawings are in 3D, during the process of parts assembly, checking for interference has been carried out carefully to avoid mismatch of components.

The entire laser cutting system could be logically divided into several building blocks. They are the laser system, the hybrid positioning system, the beam transport and auxiliary components, and the interfacing software. The development was carried out in various stages. Each of the building blocks has been tested separately before integrated to the system. This is to isolate the problem and hence to facilitate the trouble shooting process.

Initially, the laser system was integrated. The power supply, cooling system, optical resonator, vacuum pump and the root pump were among the major items in the assembly.

This was then followed by the re-designing of the positioning system and beam transport system. Hybrid configuration was chosen so that to reduce the system size in one axis, and yet to avoid the critical optical alignment in the two-axis moving beam system. When integrating the laser head and the auxiliary components, the alignment of the optics has been carried out with great care.

Finally, an interfacing software was developed in Visual Basic. This software offers a user-friendly and programming-free environment to the user in controlling the laser cutting system.

3.1 Integration of the Laser System

A FAF CO_2 laser system with closed-cycle conventionally cooled configuration and continuous wave (CW) output was adopted and optimised for this integration. This system was developed in an earlier project[20]. The resonator consists of two laser tubes aligned in one optical axis. A home-built 3-phase power supply was used to provide the high voltage for the excitation of the active gas in the discharge channel. After the electrical discharge, the hot gas medium will be removed rapidly from the discharge channel by a root pump. Heat removal is obtained by two heat exchangers placed at both the inlet and the outlet of the root pump. Throughout the operation, a small amount of the re-circulating gas medium was removed to the atmosphere by a vacuum pump while an equal amount of "fresh" active gas was filled up from the gas inlet near to the back mirror.

A schematic diagram and a photograph of the laser system are shown Figure 3-1 and Figure 3-2 respectively.

3.1.1 Power Supply

The high voltage D.C. power supply unit is a home made system based on the simple 3 phase D.C. rectified circuit as shown in Figure 3-3. It is capable of delivering a voltage up to 17kV with a current rating of 500mA. Relays A and B function as protection features that switch off the discharge channel when the high voltage suction exceeds 500mA, or when the root pump is off.

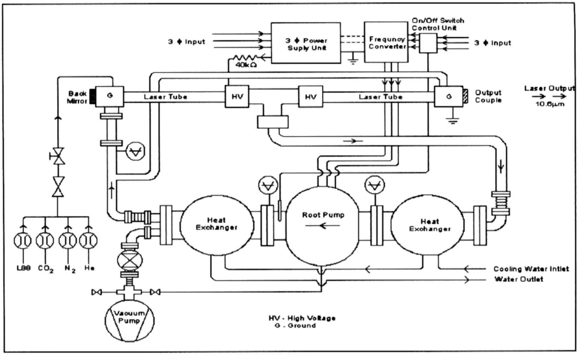

Figure 3-1: Schematic Diagram of the Closed-cycle Consecutively Cooled FAF CW CO_2 Laser

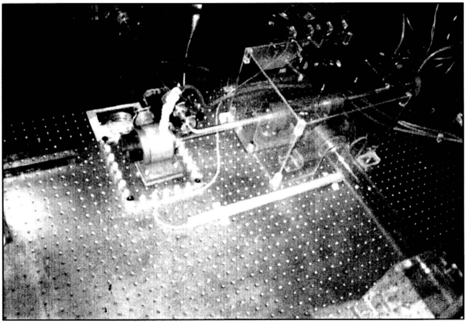

Figure 3-2: Photograph of a FAF CW CO_2 Laser System

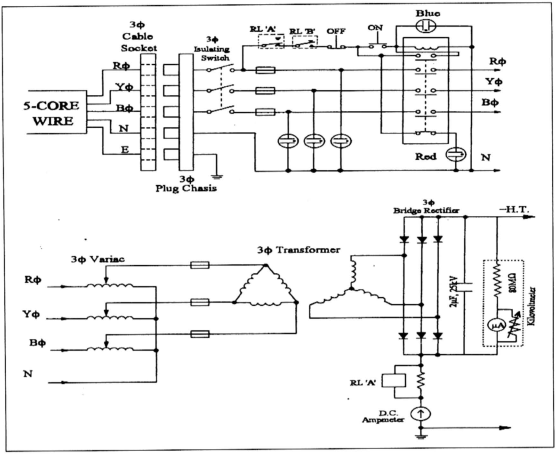

Figure 3-3: Schematic Diagram of a 3-phase Power Supply Unit

3.1.2 Optical Resonator – output coupler, back mirror

The optical resonator consists of two laser tubes aligned in the same optical axis. Each of the laser tubes consists a discharge channel. The Pyrex glass laser tubes measure 2.2cm for the outer diameter, 1.8cm for the inner diameter and 20cm in length each. However, the total length of the optical resonator measures 100cm. The back mirror is a copper plano total reflector from *II-VI Optic* which is water-cooled at the back. At the other end of the optical resonator, the output coupler is a ZnSe partial reflector with 10m concave curvature and 70% reflectivity.

In the process of the alignment, the beam of a He-Ne laser was first aligned to the optical axis of one of the laser tubes. This was done by passing through the alignment references of two circular plates each, with a centre pinhole, inserted to both ends of the tube. The second laser tube was then aligned to the He-Ne beam so that both tubes are in the same optical axis. Thereafter, the back mirror was installed and aligned so that the reflected beam passed through the pinholes again. The output coupler was then installed and the laser was operated. The fine-tuning of the output coupler was carried out slowly and carefully by observing the output power using the calorimeter.

3.1.3 Discharge Channels and Electrodes

The length of the discharge channel is set at 20cm each. The anodes consist of a grounded single side-pin at each channel while the cathodes are annular rings with negative high voltage. A perforated plate and brass mesh at the back of each side-pin introduces turbulent effect[34] to the discharge channels so that to have a better homogeneous glow discharge.

3.1.4 Cooling System and Gas Recirculating System

Two heat exchangers are employed with one cooling the heated exhaust gas generated from the discharge channels and the other removes the heat added by the root pump compression process. Figure 3-1 shows a Schematic Diagram of the Closed-cycle Consecutively Cooled FAF CW CO_2 Laser. These heat exchangers are in turn cooled by water below 10°C from a water chiller. The lowest gas temperature that can be achieved is approximately 20°C.

The re-circulating pump is a mechanical booster pump or root pump (Hick Hargreaves M53) with nominal displacement capacity of 2580m^3h^{-1} when operated at 50Hz AC. The pump is oversized to allow for subsequent scaling of the laser system.

3.1.5 Vacuum Pump

A vacuum pump (Edward E2M5) with a pumping capacity of $5.6m^3h^{-1}$ is used for the following purposes.

- To evacuate the laser chambers to the lowest pressure achievable by the vacuum pump (4x10-3mbar) before filling in the gas medium.
- To remove a small amount of gas medium from the system of which is then refilled with an equal amount of fresh gas. This would reduce the contaminant species in the laser chamber.
- To ensure the pressure of the gear chamber of the root pump is lower than the pressure of the laser chamber. This would avoid the oil in the gear chamber from contaminating the laser chamber.

3.2 Design of the Frame Structure and the Jig

Extruded aluminium struts have been used for the construction of the structural framework, as it is modular and best for prototyping. A draft of the structure is shown in the Figure 3-4.

During the rapid movement of the positioning system, vibration motion of the structure caused one initial problem at the first test-run of the laser cutting system. It amplified the resonant frequency when stimulated. Vibration[35] could range from 10Hz to as high as 250Hz. The effect of the coupling of this vibration to the bending mirrors and lenses in the beam delivery system is very severe. For instance, a mirror movement of only 20 arcsec would displace the beam by nearly 600μm at a distance of 10 ft. The initial solution was tightening the angle blocks at all corners at the joining of the aluminium profiles. Later, cross braces were installed at the diagonal corners. Consequently, effect of the stimulated vibration was reduced to a negligible level for the beam delivery system.

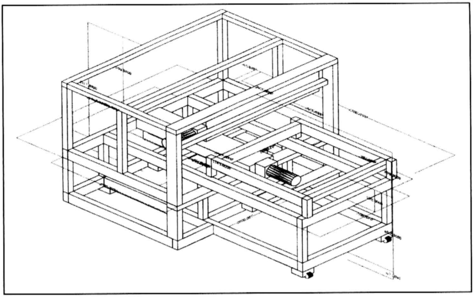

Figure 3-4: ISO View of the Structural Framework

The jig provides a workpiece cut area of 550mm by 550mm and is made of aluminium struts. An array of screws of 3 inches long has been adapted as the supporting pins for the workpiece. They are separated at 5cm apart from each other (See Figure 3-6). The reason of using the screws as the supporting pins is that they can be replaced easily after wear-and-tear, their heights can be adjusted easily to a same vertical level and cheap in maintenance. The normal force of the workpiece, i.e. the weight, sits on two sets of runner block and guide-rail ("Star" P/N: 1651 194-10 and P/N: 1605-104-31) on both the left and the right sides. The length of the guide-rail is slightly longer than twice of the jig's length, i.e. 1200mm. With these, the normal force applied on the lead screw, and therefore the stress on it would be minimised. The centre of the jig was attached to a lead screw module to which a servomotor is coupled. The lead screw module has a moving length of 570mm. At both ends of the lead screw module, limit switches that function as end switches were installed to prevent the jig from over-shooting the allowed moving length. However, at one end, another limit switch was installed at 1cm inner than the end switch and performed as a home switch.

3.3 Integration of the Hybrid Positioning System

The style of the positioning system for this project is in a hybrid configuration that the jig moves in the X-axis and the beam flies in Y-axis. A schematic diagram of the connection of the positioning control system is illustrated as below.

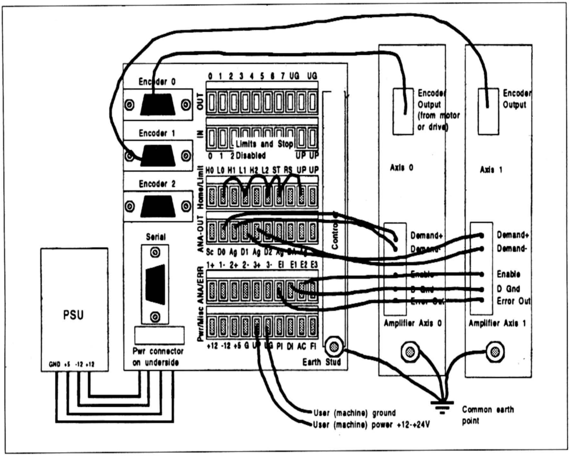

Figure 3-5: Schematic Diagram showing the Connection of the Positioning System

Figure 3-6 is a photograph of the hybrid positioning system. The details of the designing and integration are described in the subsequent sections.

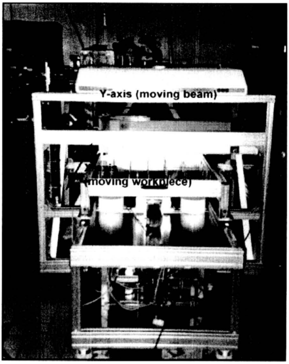

Figure 3-6: Photograph of the Hybrid Positioning System

3.4 Design of the Beam Transport System and Auxiliary Components

The beam has a moving length of 550mm corresponding to the width of the jig. Below is a photograph showing components like the bending mirror, beam shutter, laser head and beam sink.

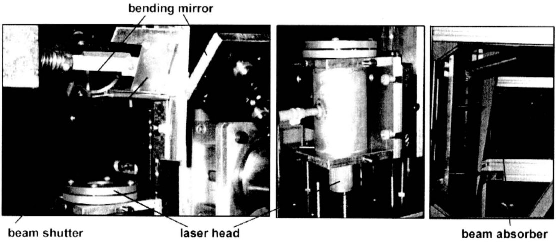

Figure 3-7: Photographs showing the Bending Mirror, Beam Shutter, Laser Head and Beam Absorber

3.4.1 Beam Folding Mirror

Three zero-phase retardant total reflectors have been used for the bending mirrors for the beam transport system. One is fixed to the frame structure while the other two are mounted to a lead screw that moves together with the laser head.

3.4.2 Beam Shutter and Beam Absorber

The beam shutter is made up of a solenoid actuator, which pushes or pulls a reflective copper plate. When it blocks the beam path, it reflects the laser beam to a beam absorber. The beam absorber is a copper tube bent to 45^0 that absorbs the beam for each pass of the internal reflections inside the tube.

3.4.3 Laser Head and Assist Gas

The laser head is of conventional single-lens (fixed-focal-length lens) design. It is mounted to a translation block, which allows 2.5cm of vertical focusing adjustment (Refer Figure 3-7). For the supply of the assist gas, the laser head is connected to a spiracle tube before connecting to the solenoid valve.

3.4.3.1 Focussing Lens

The focusing lens is a ZnSe positive meniscus lens with 5.0 inches effective focus length and 1.1 inch diameter. It can stand up to a maximum pressure of 260PSI.

3.4.3.2 Assist Gas

The assist gas can operate at a range of 1 to 8 bars and is in the configuration of nozzle centring, i.e. coaxial with the laser beam. The gases that can be manually selected from the gas stream are oxygen, compressed air and oxygen-free nitrogen. The releasing of the gas is governed by solenoid valve, which in turn is controlled by the integrated controller.

The functions of the assist gas are

- To help to remove any vapour of the material of the workpiece being cut that might be formed and might deposit on the focussing lens.
- To reduce plasma formation from above the cut front. If metal vapour is produced, it might be hot enough for ionisation to take place and thus forms a plasma "cloud" above the metal surface. The plasma is highly absorbent at the laser wavelength and can prevent part and in extreme cases, all of the laser energy from reaching the target surface.
- To speed up the cutting process in oxy-laser cutting where a reactive gas (usually oxygen) is used.
- To blow away the molten mass in laser melt cutting process.

3.4.4 Parallelism and Beam Alignment

The beam path has been aligned in such away that when it goes horizontally, it is in parallel with the motion of the laser head and the lead screw. When it finally points vertically through the laser head, it is in the axis of symmetry of the laser head. The coarse alignment was first carried out with the help of a He-Ne laser and pinhole, in about the same way when aligning the optical resonator of the CO_2 laser system in Section 3.1.2. Thereafter, the fine alignment was achieved by operating the laser system in low optical output power (less than 5W), shuttering the beam rapidly, and observing the position of the burnt mark on a ceramic plate. The laser head was moved to both ends of the lead screw module to check the beam spot consistency at the shortest and longest beam path.

3.5 Development of the Controlling Software: LaserCAM

For the controlling and monitoring of this laser cutting system, a software, code-named LaserCAM was developed. It was developed in Visual Basic version 4 and running in Windows NT 3.51. This software is written in such a way so that it is capable of doing

- bi-directional communicating with the integrated controller for information interchange through RS232 protocol, and for online checking of error status
- terminal emulation for online editing and programming
- off-line code editing and programming
- file conversion from HPGL format to MINT file format and vice-versa
- simple programme debugging functions
- simple cut simulation or cut preview prior to actual laser cut process
- housekeeping of the cut program files

A screen-shot of the LaserCAM user-interface is shown below.

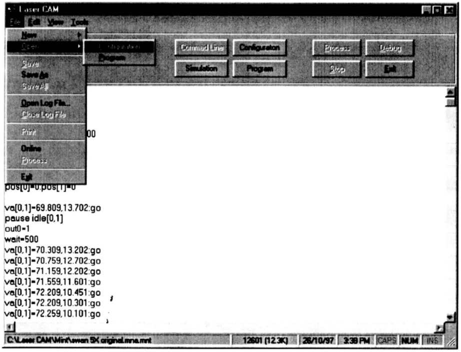

Figure 3-8: Screen-shot of the LaserCAM

3.5.1 RS232 Protocol

The integrated controller is linked to a serial port (COM2) of a PC through a serial cable. In the programming, a *MSComm* control was employed to handle the serial communication. The com port parameters are set at 9600bps baud rate, non parity, 8 data bits and 1 stop bit. The *OnComm* event was used to handle the triggered events of broken link between the PC and the integrated controller. The *CommEvent* properties that were being captured are *comEvCTS (3)* and *comEvDSR (4)*. These are the indications to the change of state in *Clear To Send* line and the change of state from 1 to 0 in *Data Set Ready* line respectively.

3.5.2 Terminal Emulation

This module makes the computer works like a terminal emulator. A terminal emulator program accepts characters input from computer keyboard and sends these characters down the serial port so that they can be interpreted and processed by the controller microprocessor. The terminal emulator program displays any information that is sent back from the controller on the computer screen. This was done by using an *OnComm's* *comEvReceive* event to trap the data capturing in the *CommInput* property and flushed all the data received to a *TextBox* control.

3.5.3 Conversion Filter (PLT to MINT)

The file format conversion was done with a conversion table that most HPGL motion commands are matched with a corresponding MINT motion commands. The x-y co-ordinates were adjusted by horizontal and vertical offsetting, then multiplied to a scale factor, and again offset horizontally and vertically. All the scale factor and offset constants were calibrated to reflect the actual size of the AutoCAD drawing. Thereafter, these coordinates were again multiplied with a scale factor and offset to a distance of user choice. In the process of file conversion, the sequence of the cut process was also optimised by finding the next nearest stroke for each completion of a cut stroke. The optimisation was accomplished using a blind search algorithm.

3.5.4 Code Editing

Basic editing features are provided in both of the online and offline editor in LaserCAM. These were achieved by manipulating the *ClipBoard* and *Screen.ActiveControl* intrinsic object in Visual Basic. Selected text in the *SelText* property of the both objects are deleted or copied among each other. In the process of online editing, each character trapped by the *KeyPress* event is passed to the Output property of the *MSComm* and flushed to the integrated controller immediately.

3.5.5 Debugging and Simulation

The debugging tool in the LaserCAM delivers feature like requesting the current cut parameter from the integrator controller, test run the cut program. Besides, the simulation function provides a sort of preview of cut profile before the actual cut process. This would minimise or eliminate totally the controller programming error, and therefore reduces the material wastage. The cut profile in MINT programming was first being analysed and then plotted to a *PictureBox* control. Each of the cut strokes was coloured with different colours for easy distinguishing so to facilitate the debugging process.

3.5.6 CAD (AutoCAD)

AutoCAD was used as the front-end of the laser in manufacturing where the 2D cut profile/shape was designed within it. Then, the drawing was output to a HPGL file (file with extension PLT) to LaserCAM and converted to MINT file.